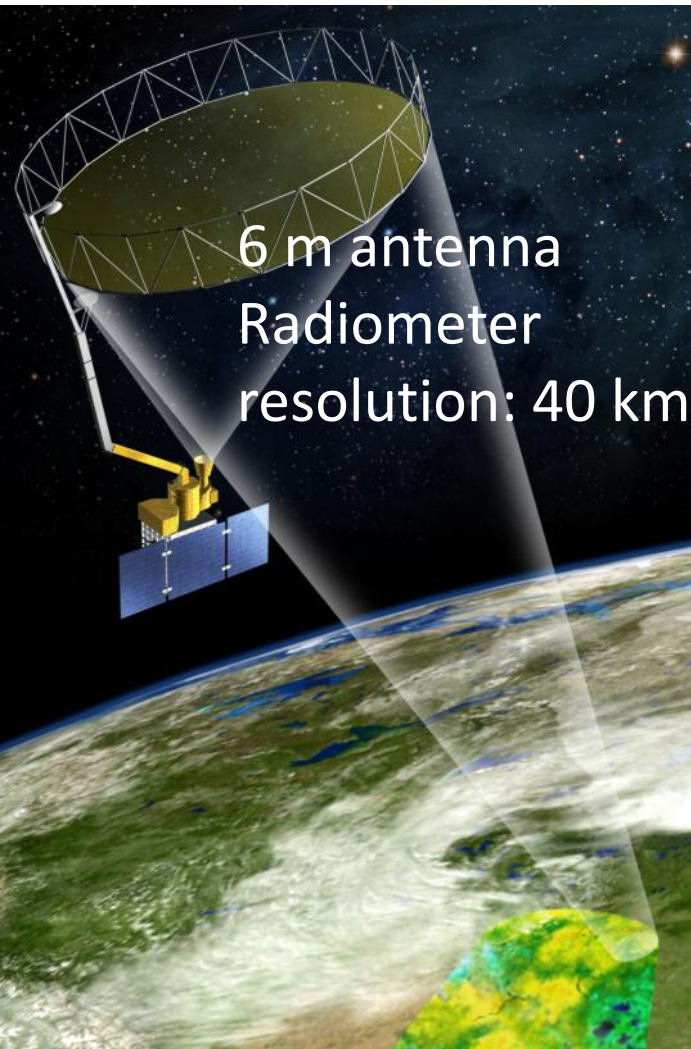# Application of SMAP data for Ocean Surface Remote Sensing

Alexander Fore

Simon Yueh

Wenqing Tang

Bryan Stiles

Akiko Hayashi

Jet Propulsion Laboratory, California Institute of Technology

PIERS 2019
June 18th, 2019

# SMAP Overview



6 m antenna
Radiometer
resolution: 40 km

*http://smap.jpl.nasa.gov/*

## Primary Science Objectives

- Global, high-resolution mapping of soil moisture and its freeze/thaw state to

  - Link terrestrial water, energy, and carbon-cycle processes
  - Estimate global water and energy fluxes at the land surface
  - Quantify net carbon flux in boreal landscapes
  - Extend weather and climate forecast skill
  - Develop improved flood and drought prediction capability

## Mission Implementation

| | |
|---|---|
| **Partners** | • JPL (project & payload management, science, spacecraft, radar, mission operations, science processing)<br>• GSFC (science, radiometer, science processing) |
| **Launch** | • January 31, 2015 on Delta 7320-10C Launch System |
| **Orbit** | • Polar Sun-synchronous; 685 km altitude |
| **Duration** | • 3 years |
| **Payload** | • L-band (non-imaging) synthetic aperture radar (JPL)<br>• L-band radiometer (GSFC)<br>• Shared 6-m rotating (13 to 14.6 rpm) antenna (JPL) |

***NRC Earth Science Decadal Survey (2007) recommended SMAP as a Tier 1 mission***

# Effects of Wind/Wave on Radar and Radiometer Signals Observed by Aquarius

- The matchup of Aquarius data with NCEP wind direction, SSMIS wind speed indicates impact of ocean wind on radar and radiometer signals.

  – The charts below indicate the signal sensitivity for the data from Aquarius beam# 2 (~39 deg incidence angle)
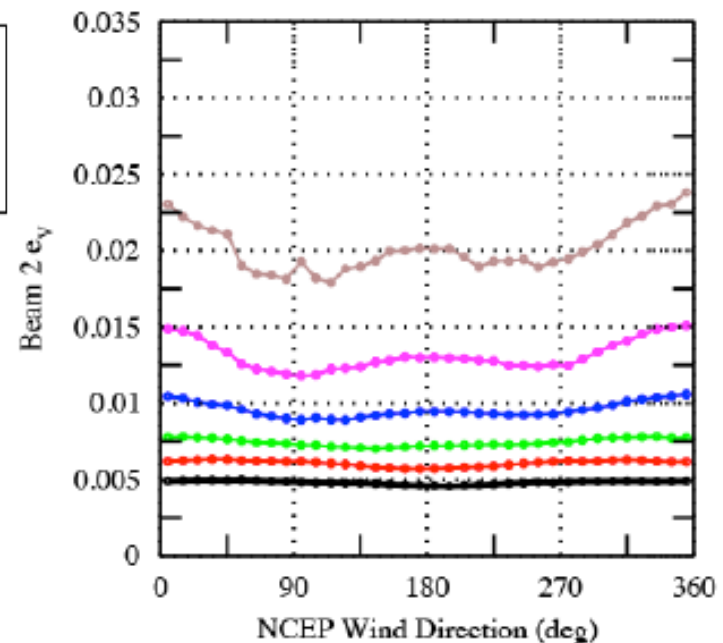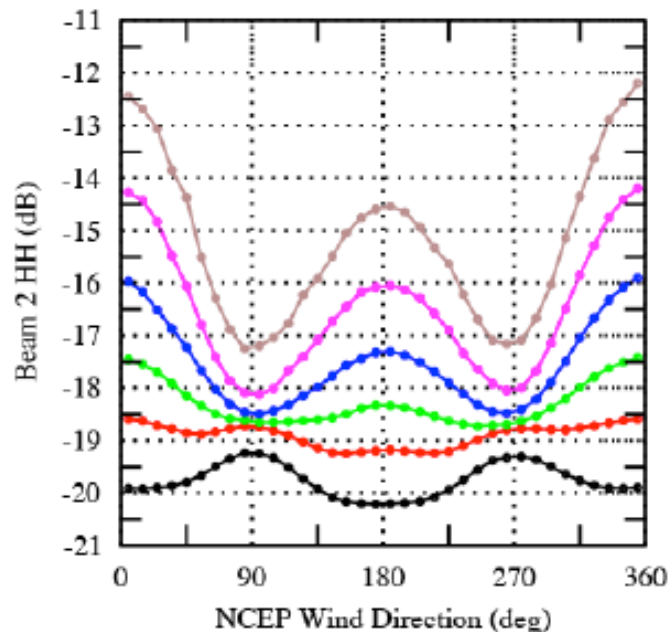


- Radar signals vary with wind speed and wind direction

  – Cosine signal changes sign at about 8 m/s

- Radio emissivity (TB/Ts) varies with wind speed and wind direction
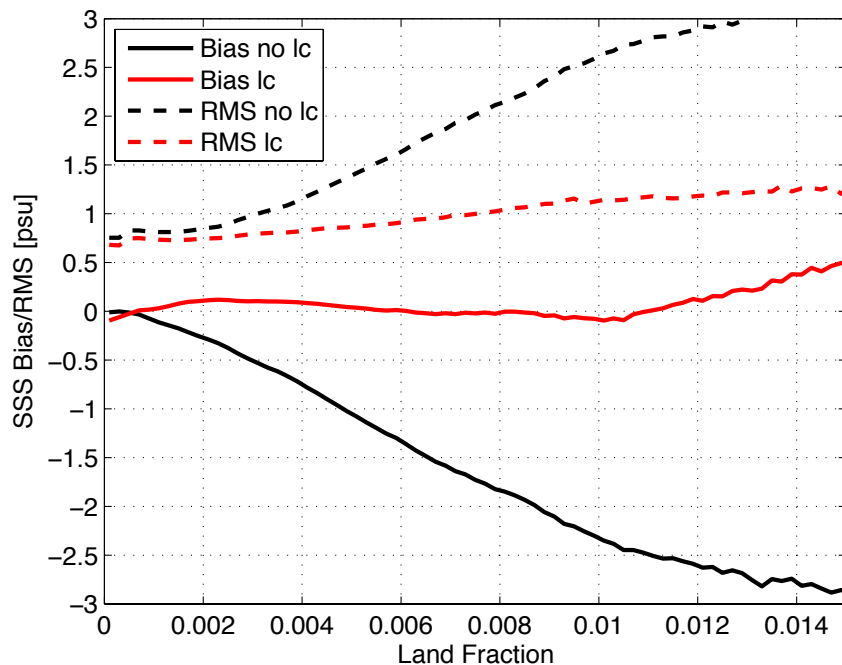
# Radiometer TB SSS and Wind Processing

- Compute delta TB using ancillary data and model
  - Average over each day; use 8 day median filtered value
  - Decimated by fore/aft x asc/dec
- Grid into a 25 km L2A swath grid just like JPL scatterometer products.
  - Gridding method oversamples observations onto the grid.
  - Effective L2 resolution is somewhat larger than 40 km, closer to 50-60 km.
- Estimate wind speed and salinity using constrained objective function minimization.
- Use NCEP GDAS forecasts for wind speed constraint; yields a significant improvement in high-winds versus interpolation analysis.

$$F(spd, sss) = \sum_i \left[ \frac{T_{B,i} - T_{B,i}^m (spd, sss, anc\_dir, anc\_swh, anc\_sst)}{NEDT_i} \right]^2 + \left( \frac{spd - spd\_anc}{1.5 m/s} \right)^2,$$
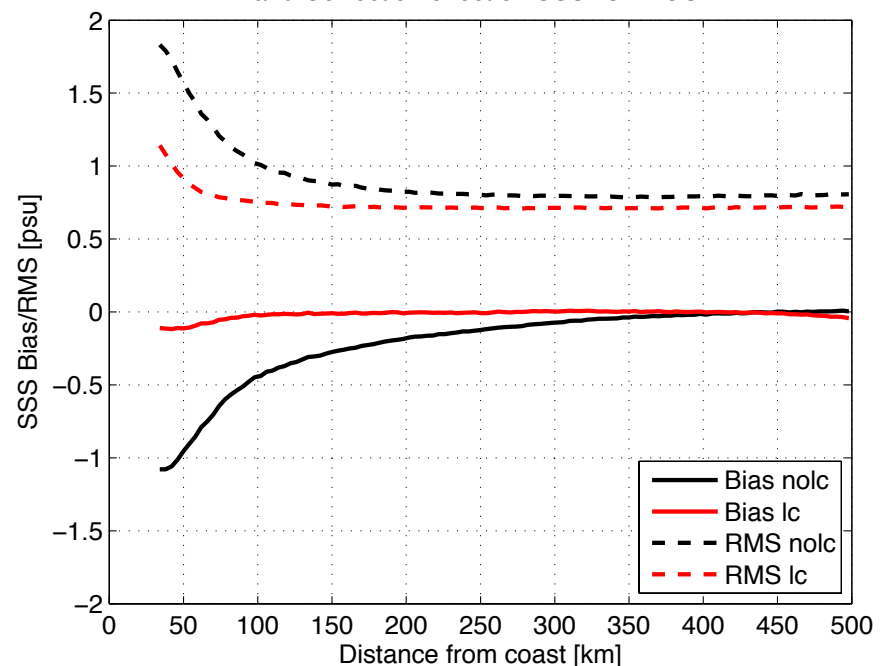
# SMAP Land Correction

- Compute land fraction ($f_{land}$) for every $T_B$ footprint.
  - Use look-up table to make problem feasible.
  - Look up table computed from nearly a year of beam integrated land fraction.
  - Function of lon, lat, cell azimuth angle.
- Generate a climatology of land $T_B$ values near to footprint.
  - Represents average $T_B$ of land not in main beam.
- Version 4 changes:
  - Retrievals allowed within 35 km from coast (v3 only > 45 km).
  - Land correction extended out to 1000 km from coast (v3 stopped at 500 km).
  - Land $T_B$ tables updated with 2 years of data.
  - Land fraction available as L2B and L3 dataset for **user-configurable land rejection**.
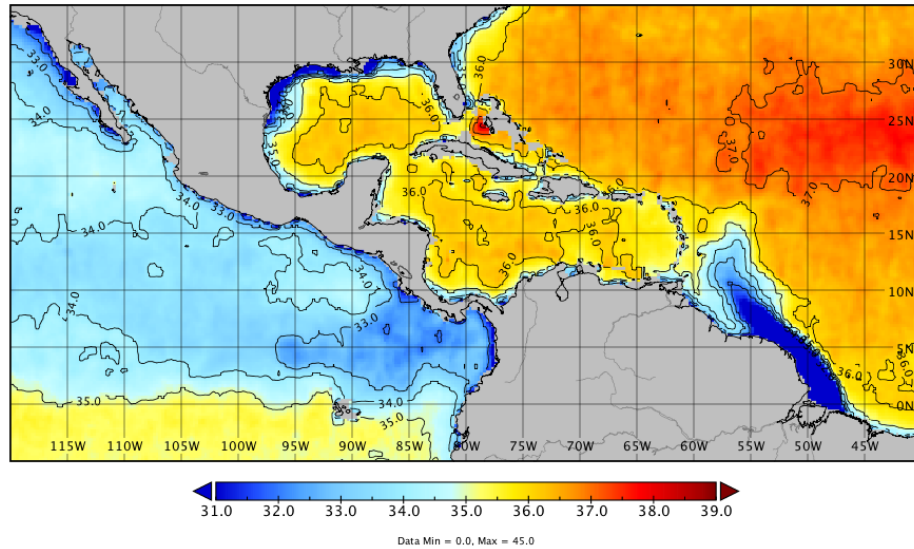


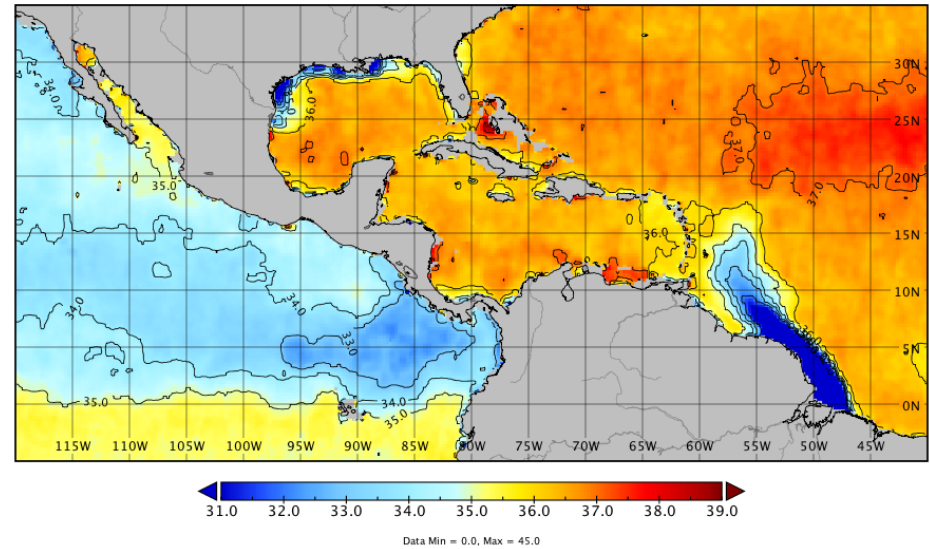Land Correction effect on SSS vs HYCOM

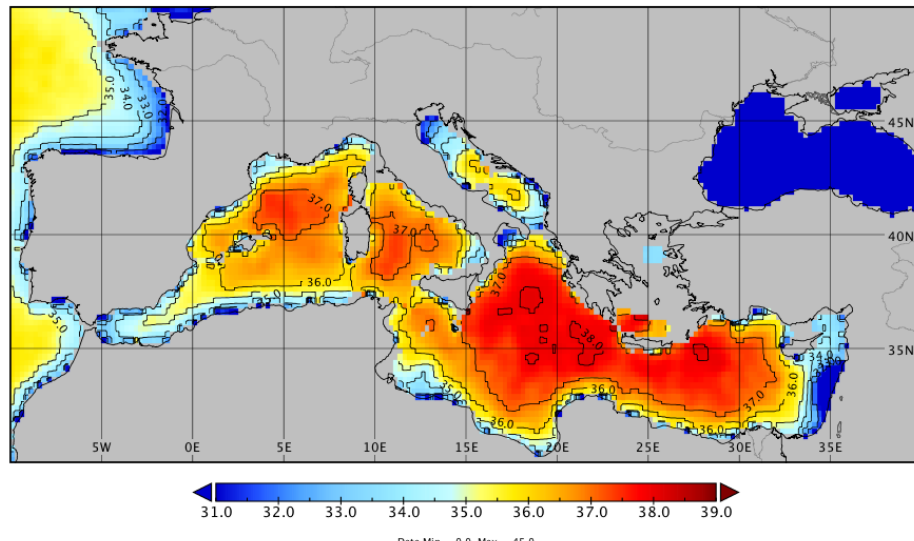# Monthly SSS maps without (left) and with (right) land correction



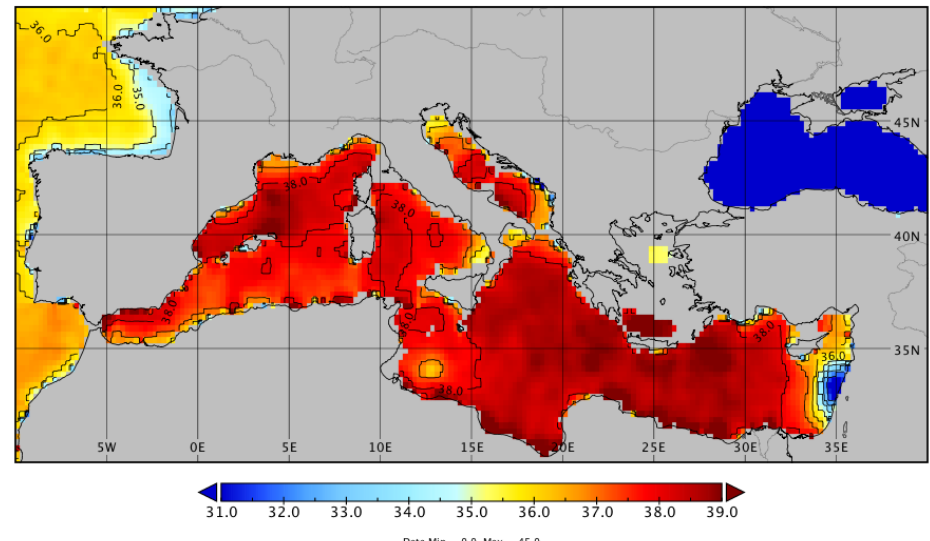SMAP sea surface salinity May 2015 [PSU]; Without Land Correction

SMAP sea surface salinity May 2015 [PSU]; With Land Correction

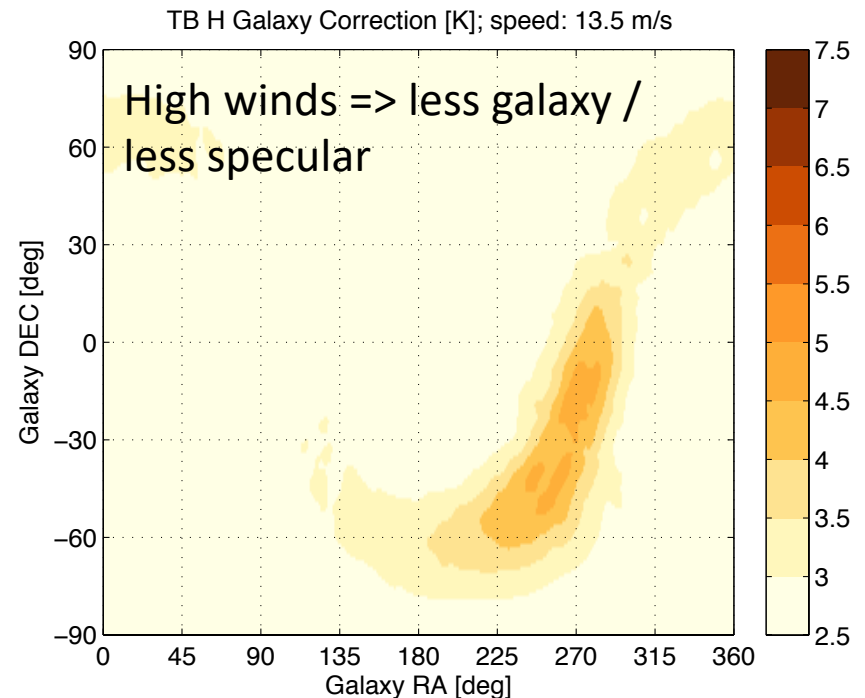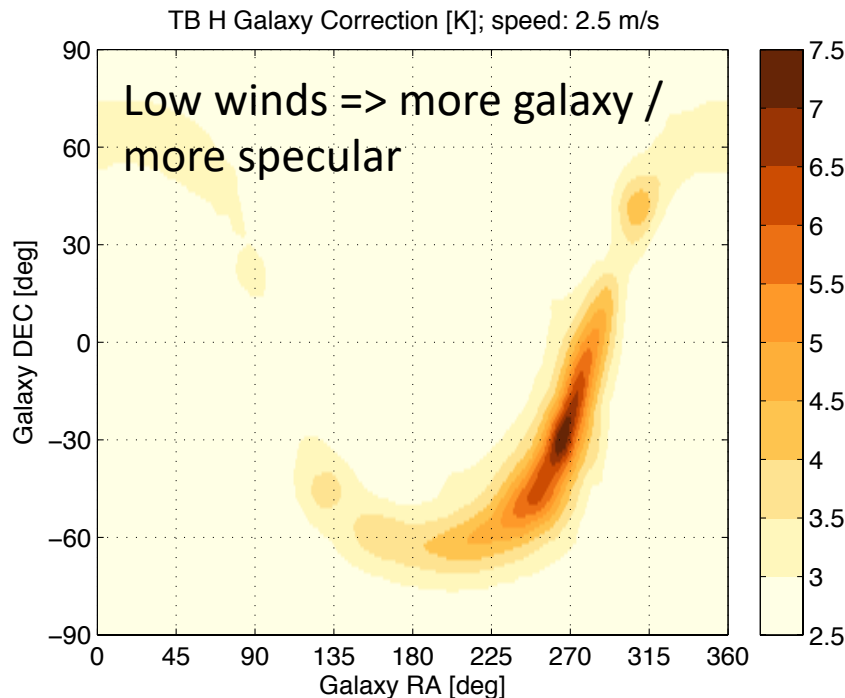SMAP sea surface salinity May 2015 [PSU]; Without Land Correction

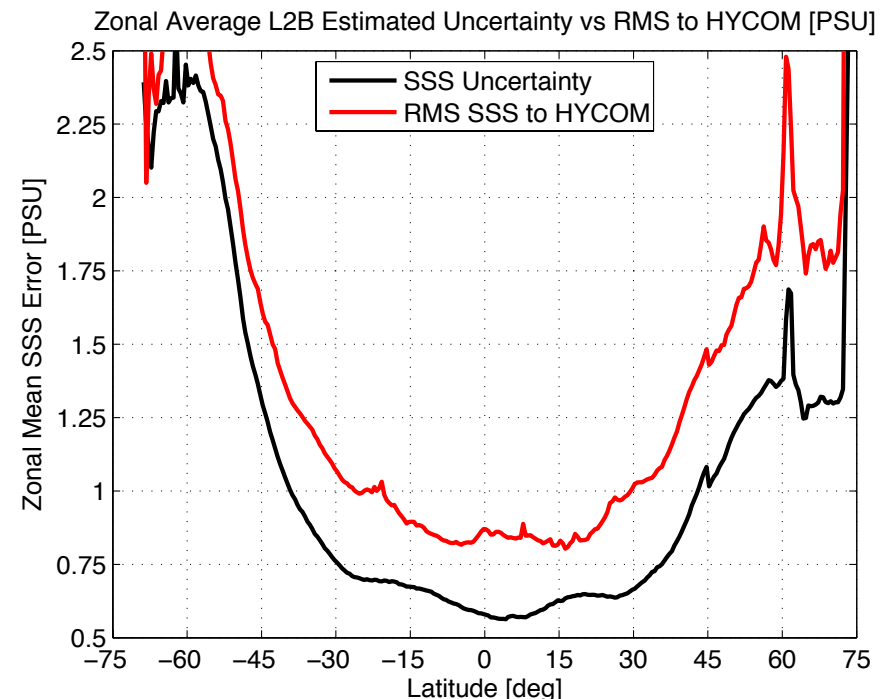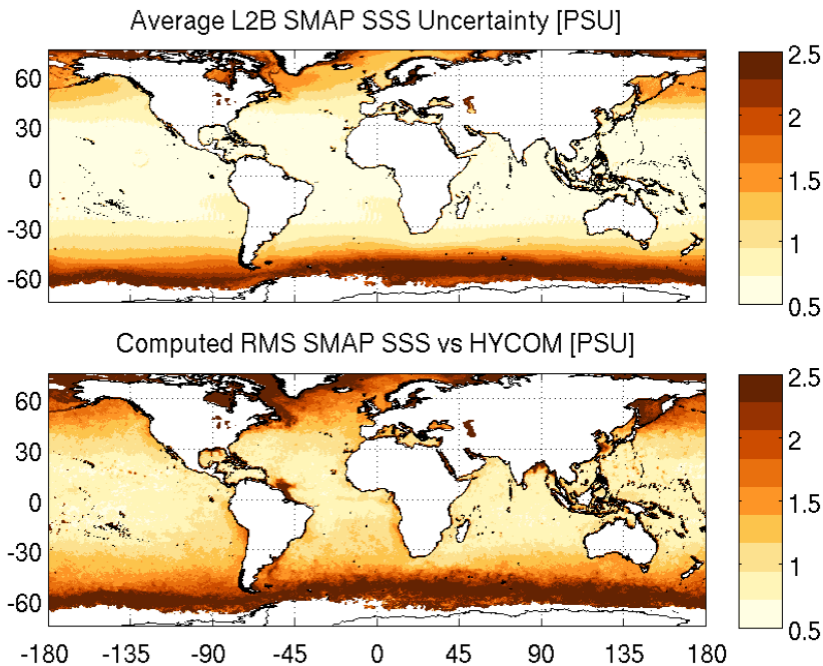SMAP sea surface salinity May 2015 [PSU]; With Land Correction

# SMAP Galaxy Correction

- Operational SMAP galaxy correction is not sufficient for salinity processing.
  - Operational correction is not a function of wind speed but rather a constant.
  - Direct estimation of galaxy is possible with SMAP unlike Aquarius (two look).
- With two years of SMAP; match fore look to aft look on ocean:
  - Use ancillary galaxy map to select "hot" look and "cold" look.
  - TB delta of hot-cold look nearly all due to galaxy* (after removal of sun, moon, wind direction).
  - Bin-average hot-cold delta as function of hot look galaxy RA, DEC, and surface wind speed.



TB H Galaxy Correction [K]; speed: 2.5 m/s

Low winds => more galaxy / more specular

TB H Galaxy Correction [K]; speed: 13.5 m/s

High winds => less galaxy / less specular

# Estimated SSS Uncertainty

- Use width of objective function minima for each SWC.
  - Captures all known information (predicted variance via NEDT).
  - Captures effects of all unknowns via residual mismatch of measurements to model function (can't model it if we don't know it).
- For L3 use propagation of variance and assumptions about correlation of adjacent SWCs and L3 binning.
- Allows for user-configurable quality control.



Average L2B SMAP SSS Uncertainty [PSU]

Computed RMS SMAP SSS vs HYCOM [PSU]

Zonal Average L2B Estimated Uncertainty vs RMS to HYCOM [PSU]

# Level 3 Processing

- L2B data are aggregated on a 0.25 x 0.25 geographic grid.
- Two flavors of L3 data:
  - Moving 8-day time average centered on 1200 UTC +/- 4 days.
  - Monthly time average: all orbits that start in that month.
- Use Gaussian weighting to aggregate L2B swath data onto fixed grid:
  - Half-power radius of 30 km
  - Cut-off radius of 45 km
- SMAP L3 resolution slightly larger than 60 km; Aquarius was ~ 100-150 km.
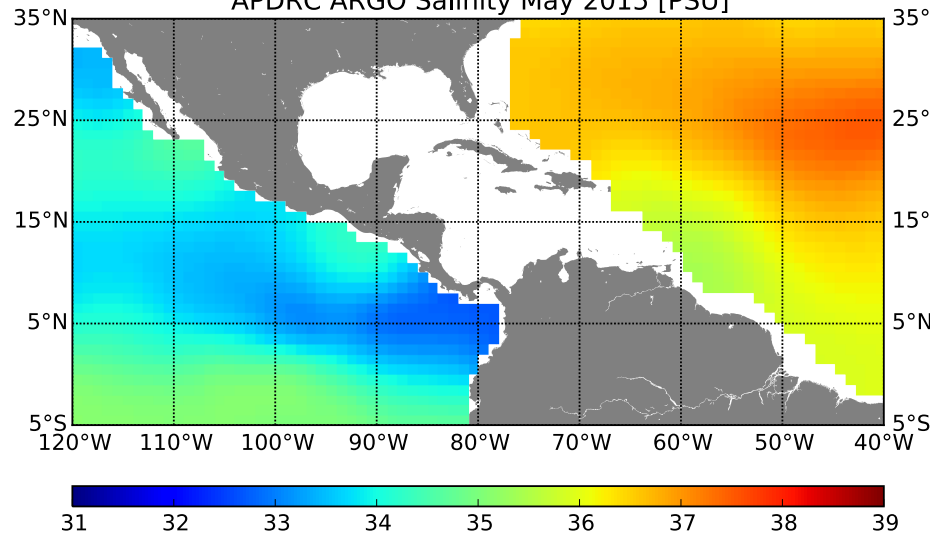
Sea Surface Salinity Maps May 2015
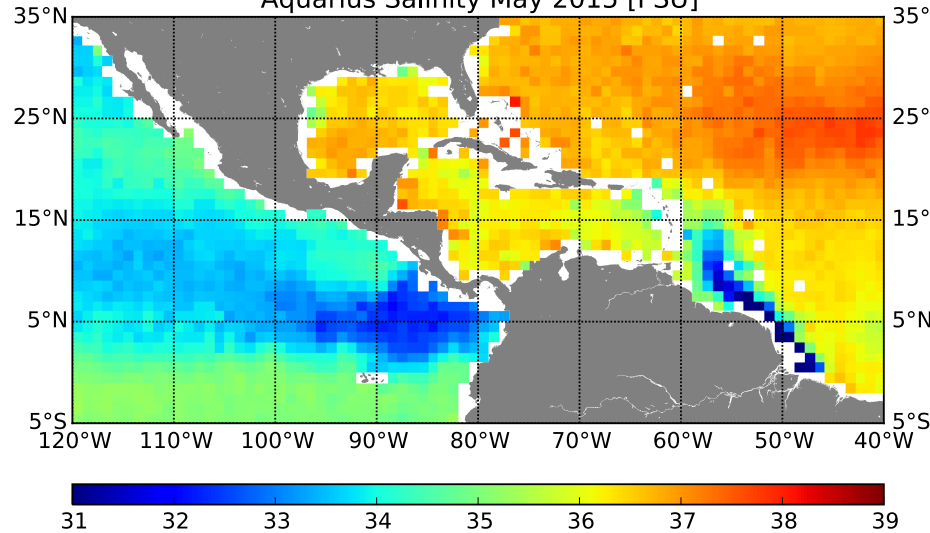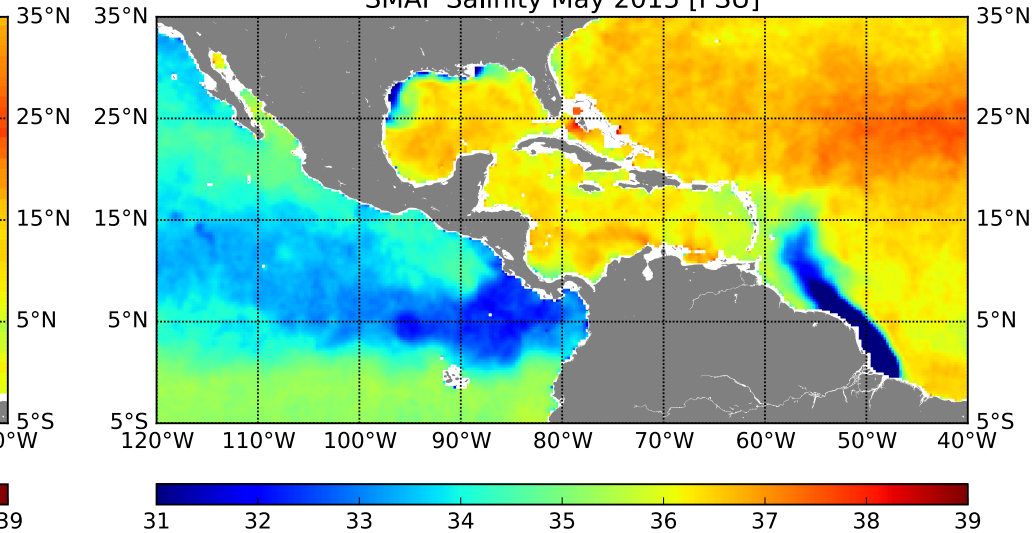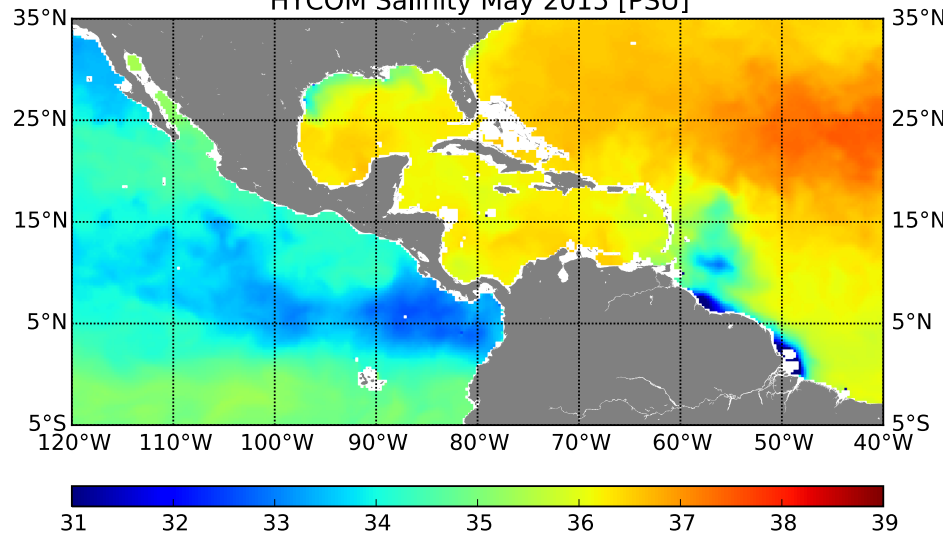
# SMAP L3 versus ARGO

- Bias/STD/RMS of 1x1 deg averaged monthly SMAP V4:
  - ARGO SIO (black)
  - ARGO ADPRC (red)
  - JAMSTEC (green)
- *JPL SMAP has monthly STD of just under 0.2 PSU – meeting Aquarius science requirements.*



(a) Bias (SMAP−Argo)

SIO    0.003 PSU
APDRC  0.008 PSU
JAMSTEC −0.002 PSU

PSU

Time (April 2015 − Dec. 2017)

(b) Std. of difference

SIO    0.199 PSU
APDRC  0.226 PSU
JAMSTEC  0.222 PSU

PSU

Time (April 2015 − Dec. 2017)

(c) RMSD

SIO    0.203 PSU
APDRC  0.230 PSU
JAMSTEC  0.225 PSU

PSU

Time (April 2015 − Dec. 2017)
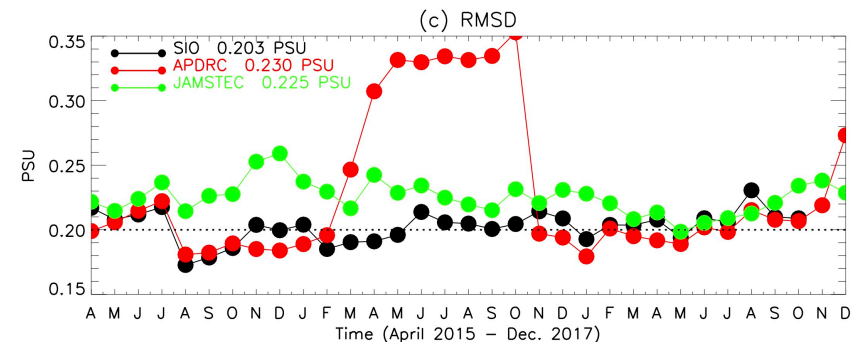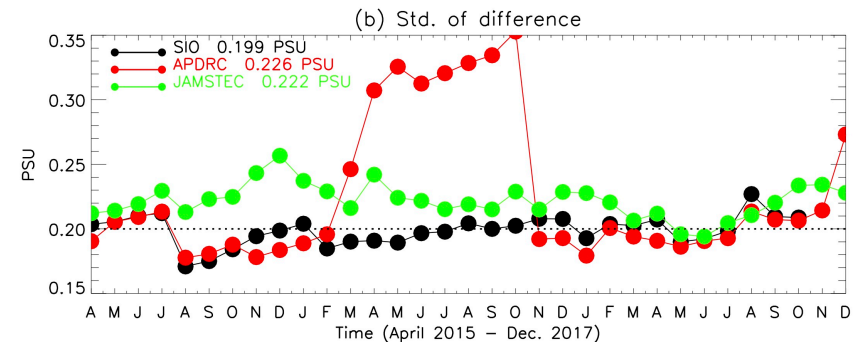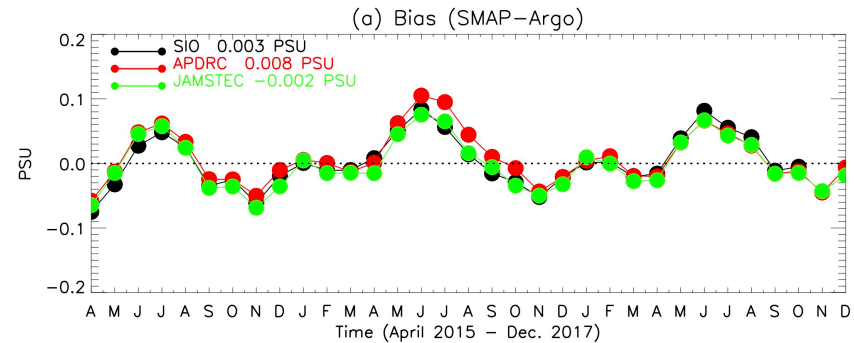
# Summary of SMAP and SMOS vs. Buoy

- Excellent agreement between SMAP and mooring SSS in the tropical oceans based on the summary of statistical differences between them for 29 buoys with contiguous time series of SSS during April 2015 and August 2016.
- OI: 45 km search radius and 30 km half power

| SMAP | Bias | Standard Deviation | Correlation |
|---|---|---|---|
| 15 day average | 0.07 psu | 0.22 psu | 0.73 |
| 30 day average | 0.05 psu | 0.17 psu | 0.80 |

| SMOS | Bias | Standard Deviation | Correlation |
|---|---|---|---|
| 15 day average | -0.15 psu | 0.26 psu | 0.63 |
| 30 day average | -0.16 psu | 0.22 psu | 0.71 |

# SMAP L-band Radiometer Data For Severe Weather – Ocean Vector Wind

- L-band brightness temperature useful for hurricane wind speed retrieval using two looks, dual-pol TB
- Using HYCOM SSS as ancillary

$$C(w,\phi) = \sum_{i=1}^{2} \frac{(T_{BVi} - T_{BVMi})^2}{\Delta T^2} + \sum_{i=1}^{2} \frac{(T_{BHi} - T_{BHMi})^2}{\Delta T^2}$$



SMAP TB-only Wind Speed [m/s]; 20150501 to 20150503
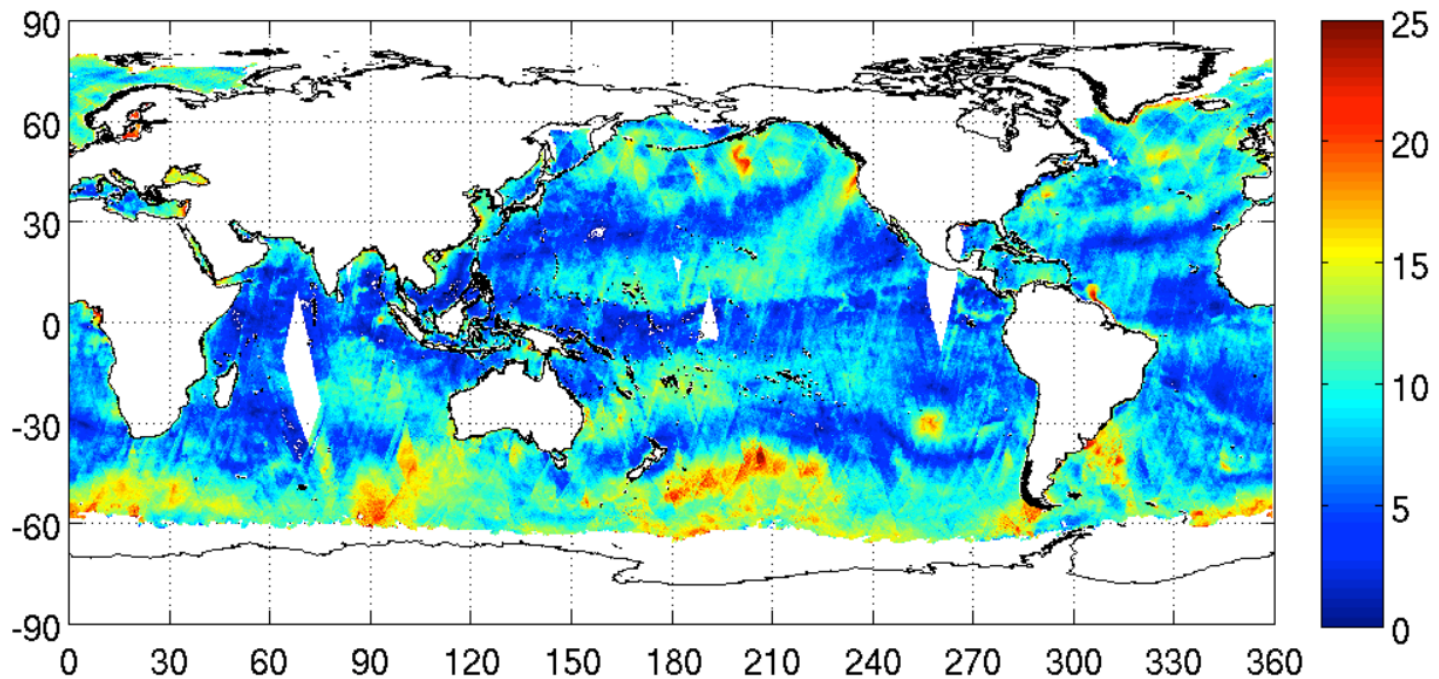
# SMAP / RapidScat / WindSat collocations (30m)

- Only extract joint collocations within 30 minutes of SMAP.
  - 3.7 million matchups.
- Use WindSat to remove rainy observations.
- Find nearly zero speed bias up to 26 m/s, not enough data past that.
- 2d histogram does not show any trend of increasing SMAP speed bias as compared to RapidScat



SMAP/RapidScat Wind Speed Matchups
WindSat / SSMI/S indicate no–rain; Within: 30 minutes

2D Histogram of SMAP/RS wind Speeds [dB Counts]
Within: 30 minutes; 3705445 total
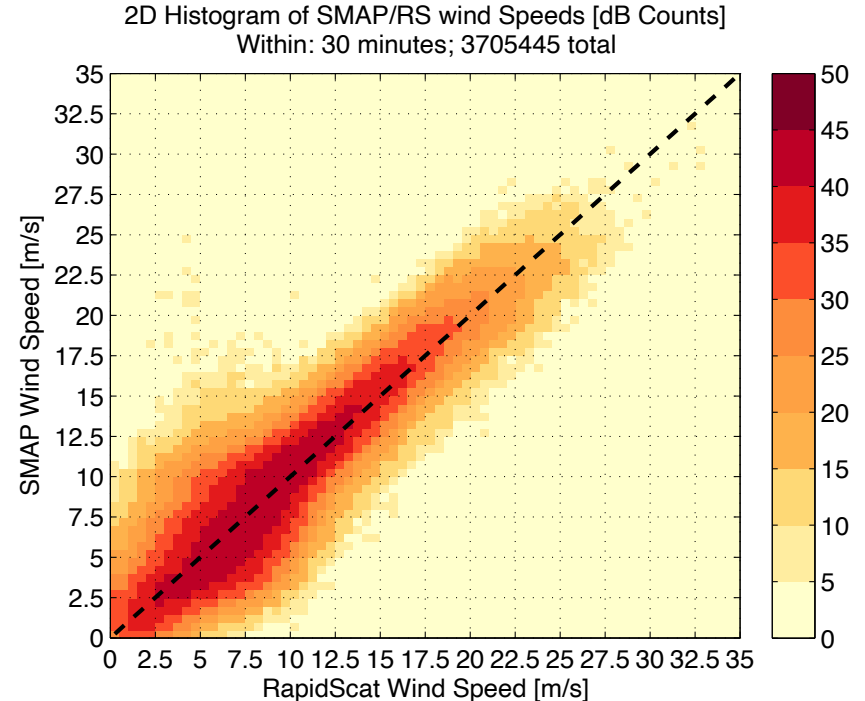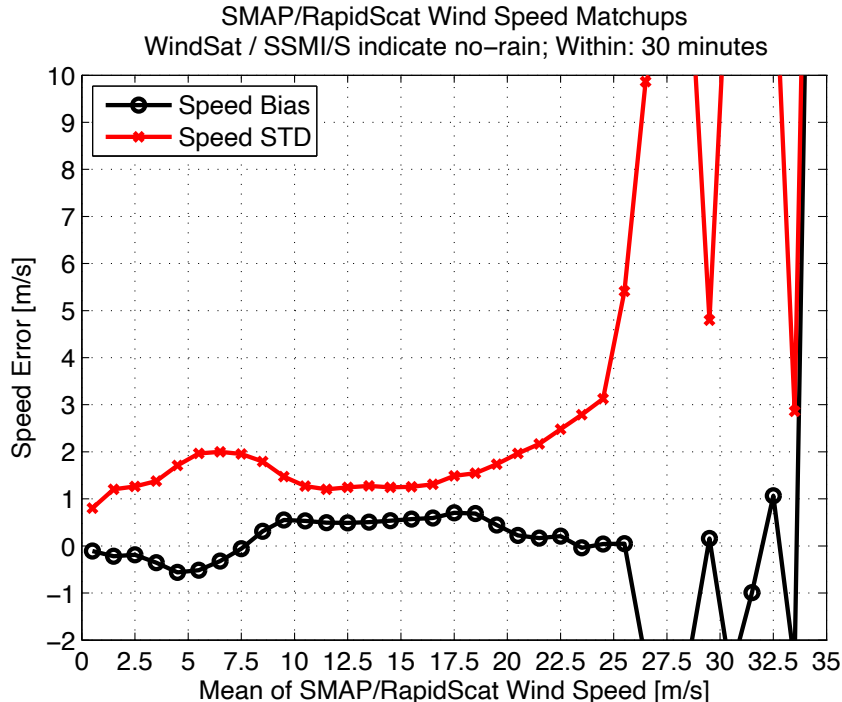
# SMAP / RapidScat / WindSat collocations (90m)

- Same as previous with 90 minute collocation time.
  - 13 million matchups.
- Find very small speed bias up to 30 m/s (order 1 m/s).
- 2d histogram show data distributed near 1:1 line, no evidence of large positive SMAP bias near 30 m/s as compared to RapidScat.



SMAP/RapidScat Wind Speed Matchups
WindSat / SSMI/S indicate no–rain; Within: 90 minutes

2D Histogram of SMAP/RS wind Speeds [dB Counts]
Within: 90 minutes; 13306873 total
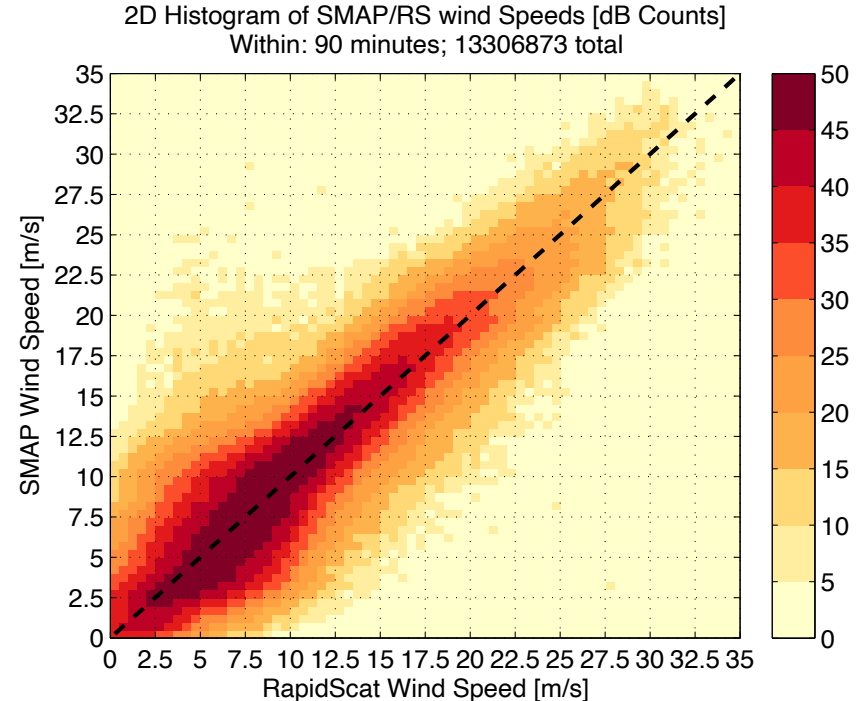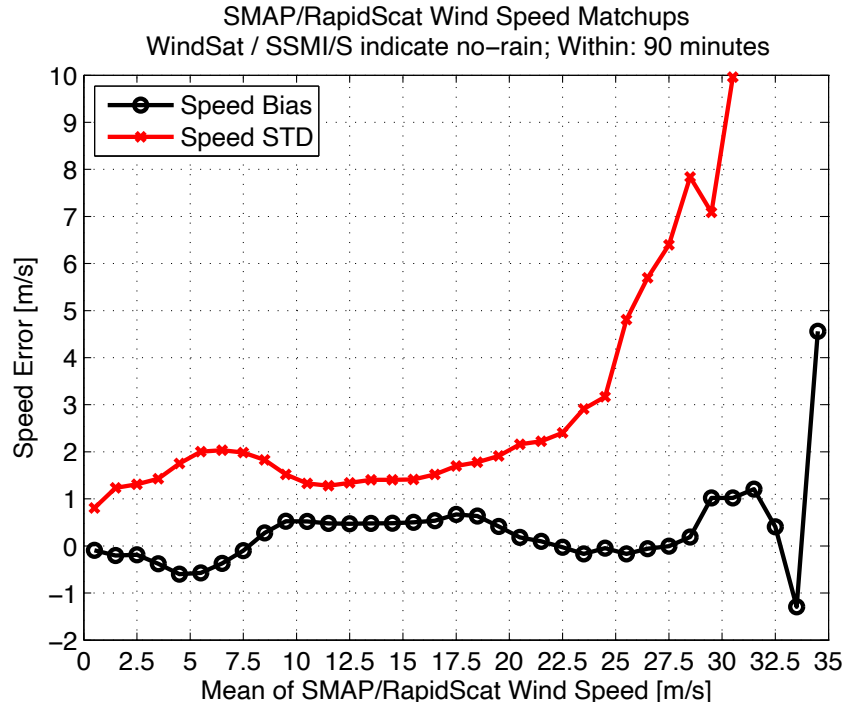
SFMR vs SMAP for PATRICIA at 2015−10−23 13:10:13
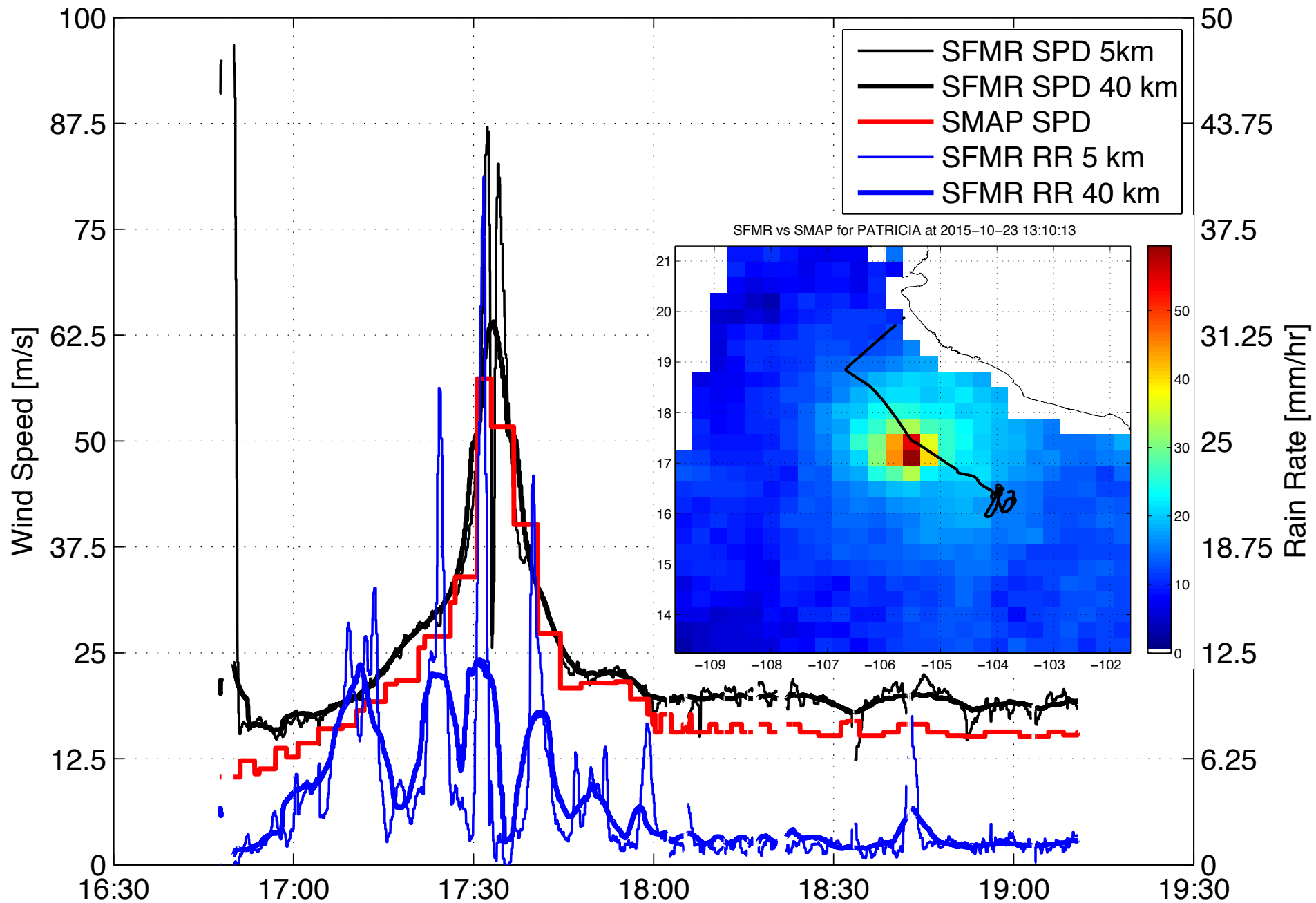
SFMR vs SMAP for Ignacio at 2015−08−30 03:53:05
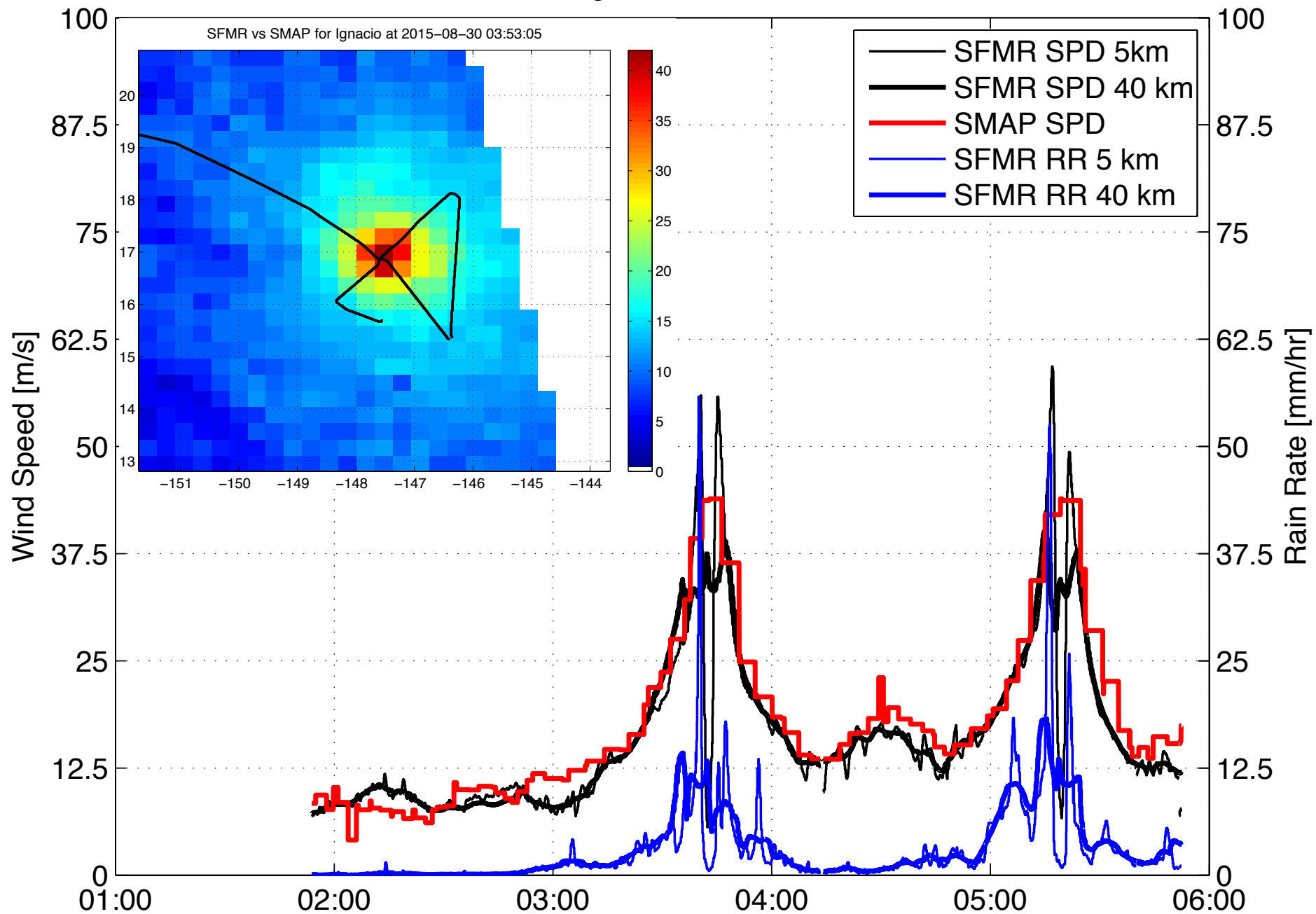
# SFMR Matchups for 2015-2017

| DTime | SFMR > 20 m/s | | | | SFMR > 25 m/s | | | |
|---|---|---|---|---|---|---|---|---|
| | Counts | Bias | STD | Corr | Counts | Bias | STD | Corr |
| 15 | 43 | 0.88 | 3.10 | 0.85 | 18 | 0.66 | 3.82 | 0.85 |
| 30 | 79 | 1.61 | 3.54 | 0.81 | 38 | 1.69 | 3.99 | 0.77 |
| 45 | 116 | 1.51 | 3.54 | 0.80 | 58 | 1.59 | 4.05 | 0.73 |
| 90 | 261 | 1.15 | 3.15 | 0.84 | 102 | 1.90 | 3.80 | 0.73 |
| 180 | 523 | 1.21 | 3.23 | 0.81 | 196 | 1.93 | 3.97 | 0.69 |
| 240 | 632 | 0.90 | 3.33 | 0.79 | 245 | 1.31 | 4.23 | 0.63 |
| 300 | 791 | 0.58 | 3.66 | 0.74 | 316 | 0.52 | 4.66 | 0.58 |
| 360 | 954 | 0.20 | 3.96 | 0.73 | 363 | 0.38 | 4.63 | 0.60 |

- Average SFMR along-track to 60 km, pick point of nearest approach to SMAP cell.
- Use best-track to shift SFMR tracks to SMAP observation time.

# SMAP Wind Radii

- We validate against the ATCF B-deck datasets.
- Use three years of data: 2015-2017.
- For each SMAP cyclone hit:
  - Extract chip of wind field centered on best-track location.
  - Within each compass quadrant compute contours for (34, 50, 64) knot wind thresholds.
  - Find longest connected contour in each compass quadrant for each threshold speed and compute the 90% threshold value of distance of line to best-track position.

# Wind Radii Results

- ## SMAP wind radii are in reasonable agreement with ATCF B-deck radii:

  - ATCF wind radii estimates have ~ 20-40% error.

  - Good correlation to ATCF radii.

  - SMAP relatively unbiased.



SMAP wind radii versus NHC wind radii

Legend (left plot): 34kt, 50kt, 64kt

SMAP wind radii versus NHC wind radii

- 34 kt; Median: −0.04; CDF68: 42.14; CORR: 0.86
- 50 kt; Median: 1.63; CDF68: 24.99; CORR: 0.65
- 64 kt; Median: 8.96; CDF68: 21.63; CORR: 0.64
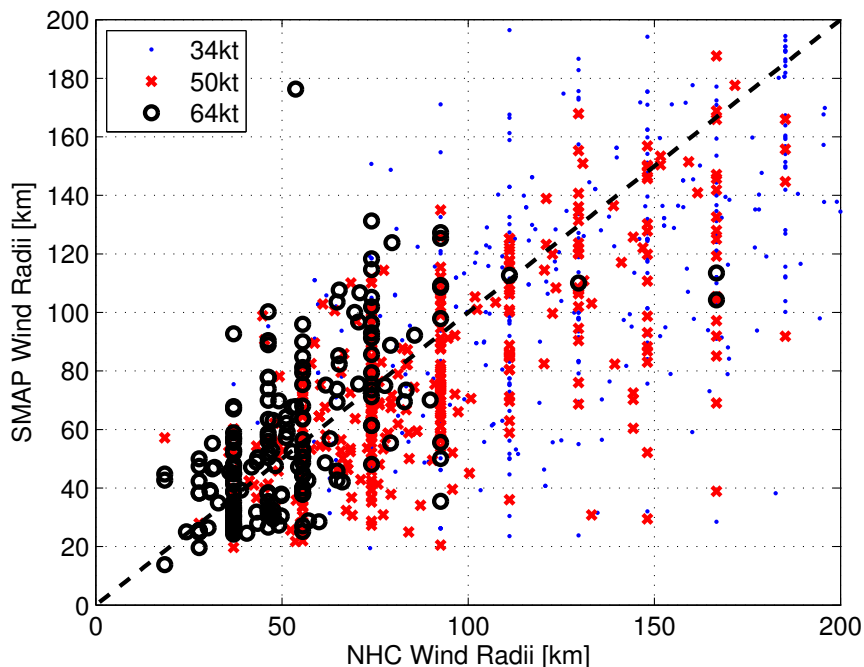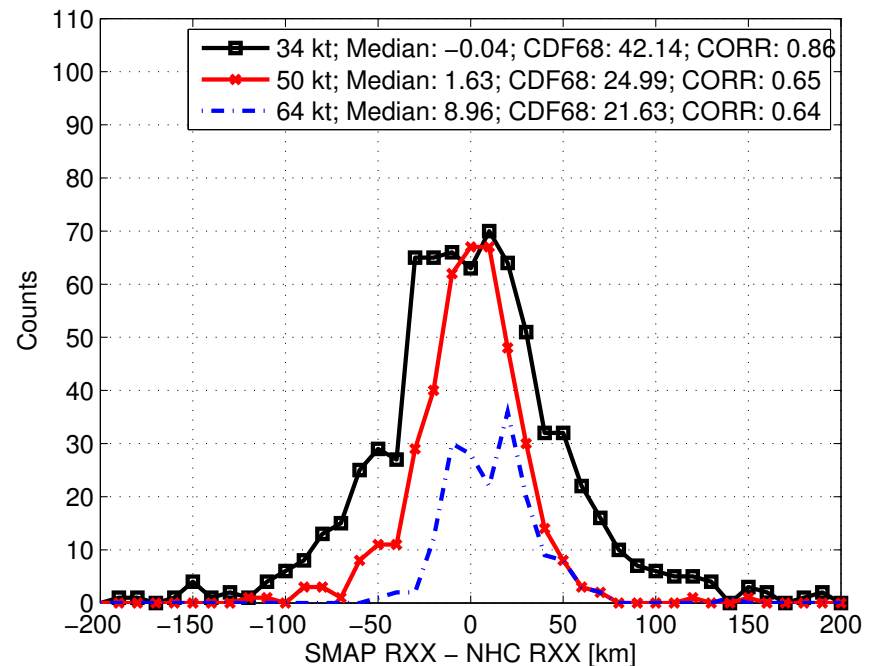
SMAP's radar mode operated for two months
With the SAR we can see into the eye of cyclones
Super Typhoon Noul; JTWC indicates 71 m/s
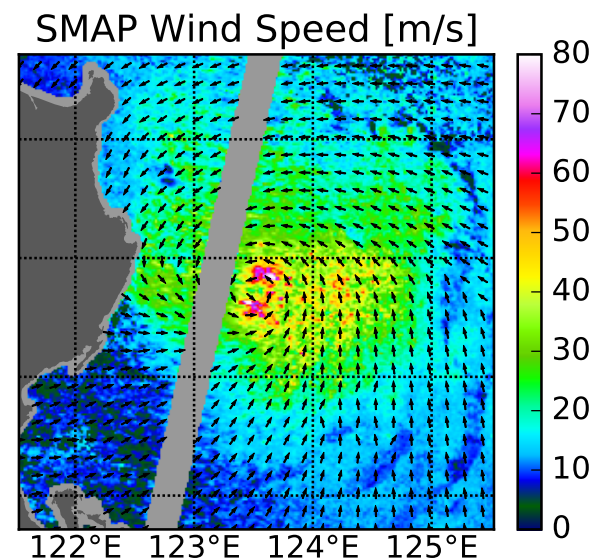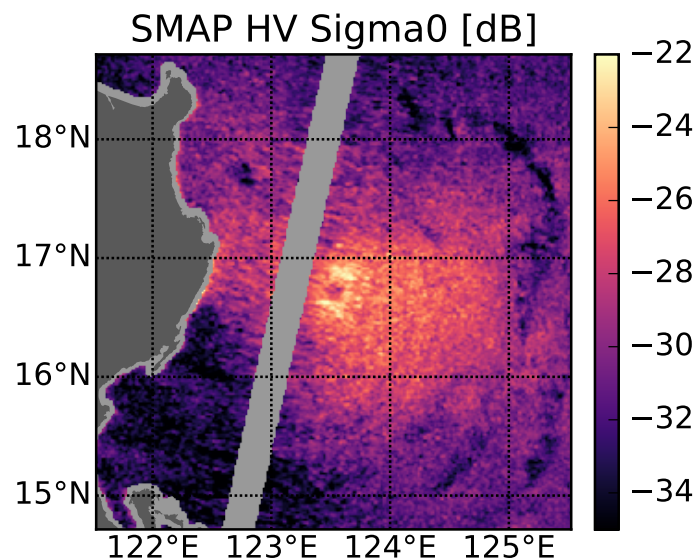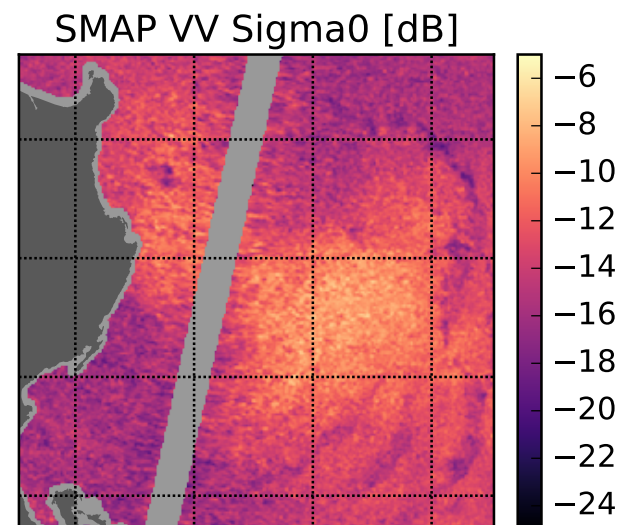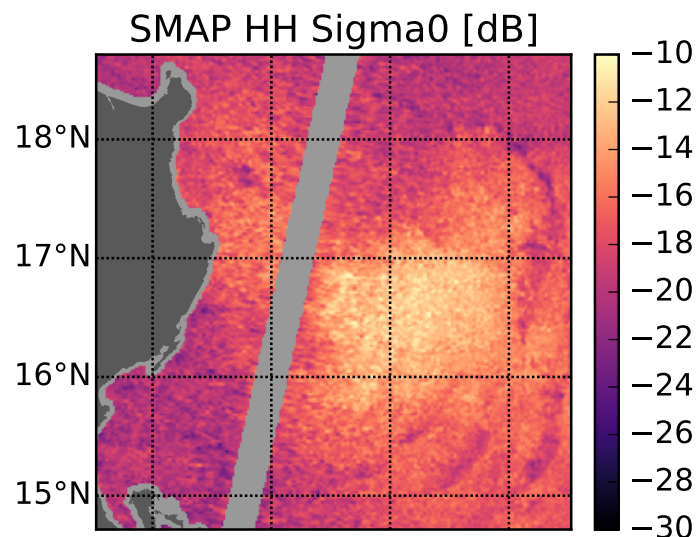
# Summary

- Salinity:
  - SMAP radiometer-only data is capable of providing a ocean salinity data product that meets the Aquarius science requirement of 0.2 PSU: (v4.0*)
    - 0.2 PSU STD as compared to SIO ARGO at 1x1 deg monthly scale.
    - 0.17 PSU STD as compared to tropical moored buoys at 1x1 deg monthly scale.
  - Version 4 improves on previous algorithm:
    - Improved coastal correction + SSS in very large lakes.
    - Extended range of SSS retrievals to 45 PSU.
    - Improved roughness correction using forecast data.
    - Addition of **land fraction** and **SSS estimated uncertainty** at L2 and L3 for **user-configurable data rejection**.
- Extreme winds:
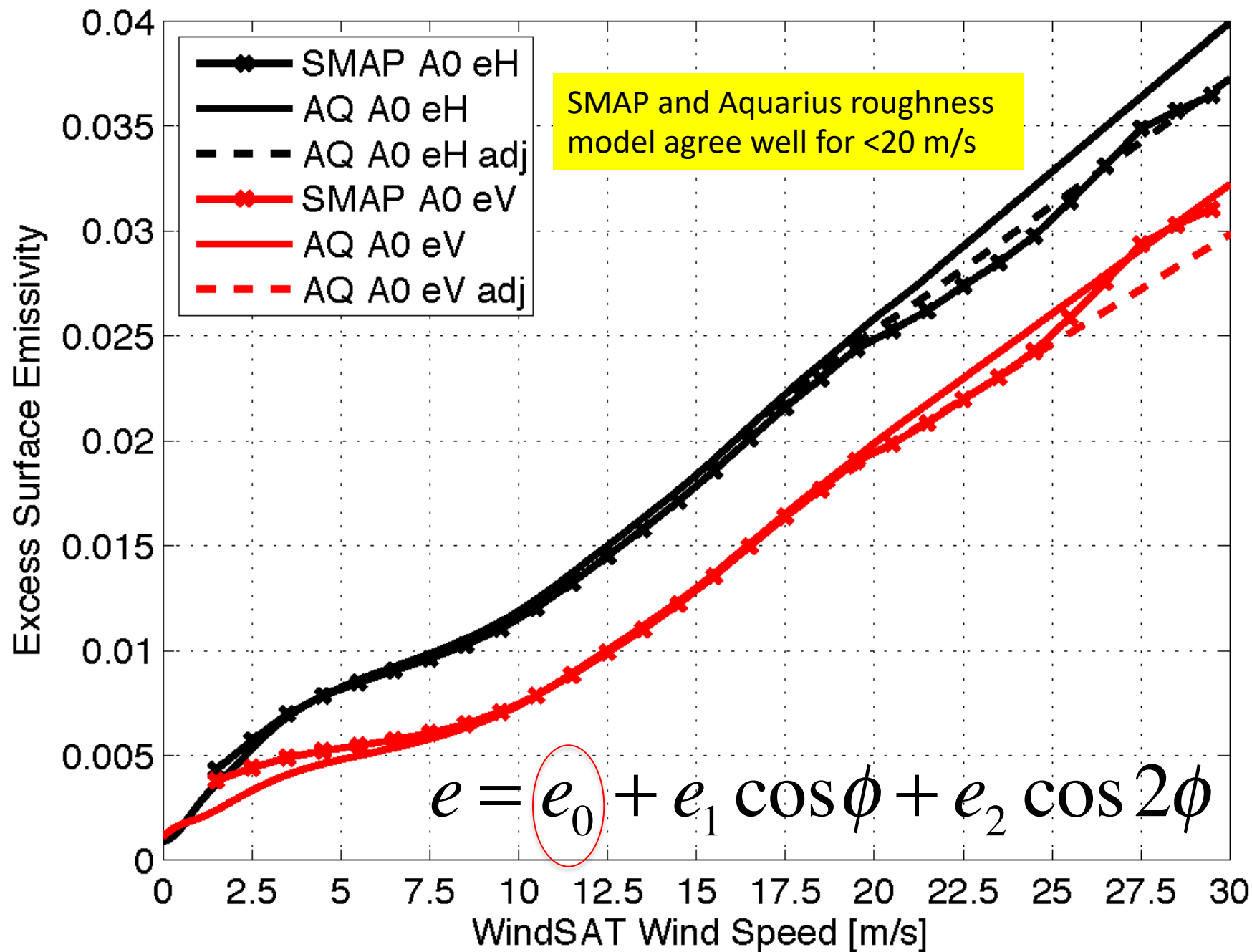  - Comparisons to RapidScat show SMAP L-band passive winds are unbiased between 20-30 ms$^{-1}$
    - Storm force wind estimates from SMAP are unbiased.
  - Using SFMR we find good agreement to about 40 ms$^{-1}$
    - Positive bias between 30-40 ms$^{-1}$ no larger than 3 ms$^{-1}$
    - Overall STD as compared to SFMR is on the order of 4 ms$^{-1}$ for wind speeds larger than 25 ms$^{-1}$
  - Comparisons to ATCF B-deck datasets shows SMAP provides reasonably unbiased size estimates with good correlation to ATCF values.
  - **Overall, SMAP can provide valuable information on Tropical Cyclone size and *averaged* intensity.**

- *Version 4.0 is best version to date; working on improved V4.3 now.*
- Data are available at http://podaac.jpl.nasa.gov
  - L2B NRT data have about 4.5 hour median latency.
  - L2B with a 3 day delay.
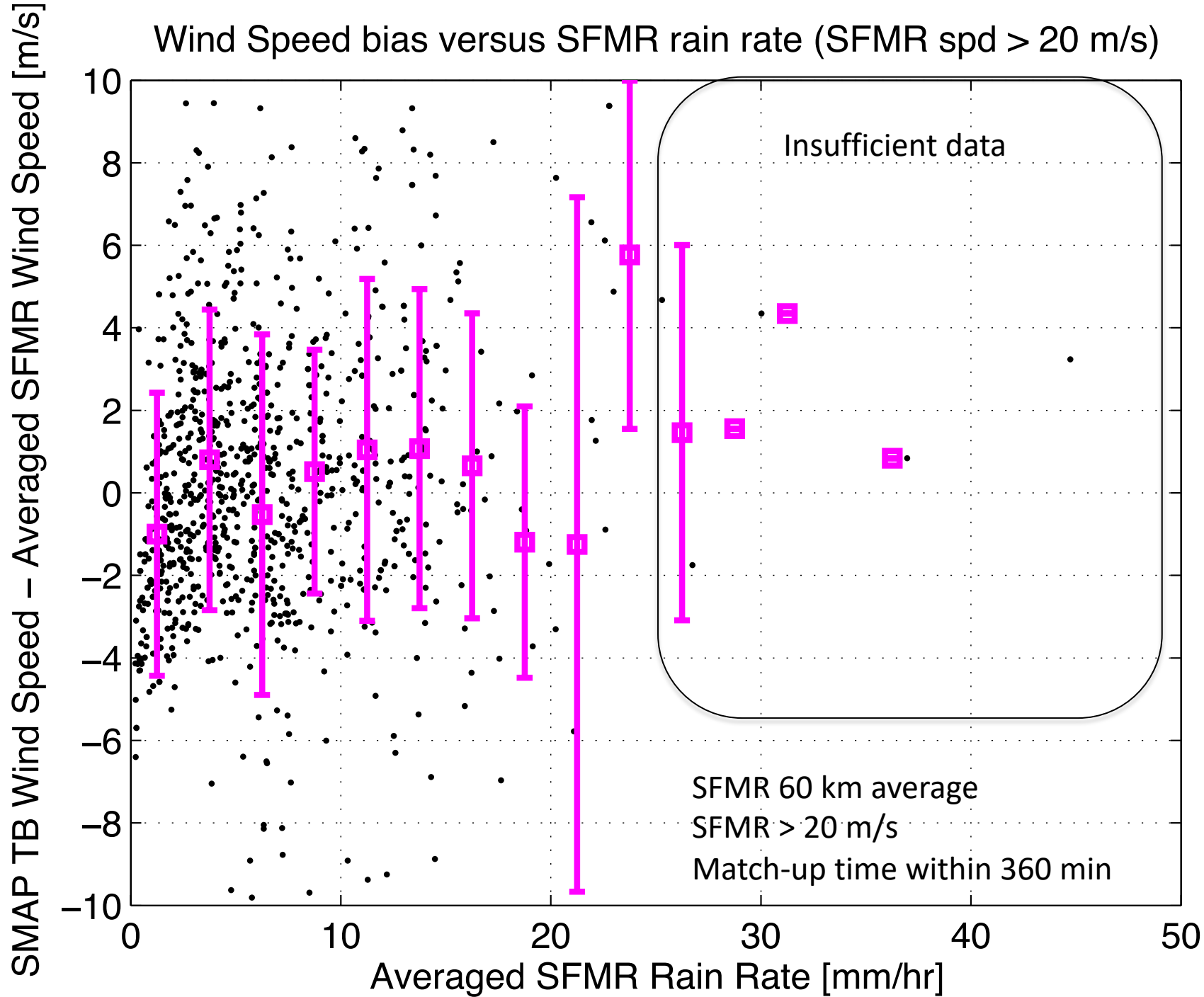  - L3 with a 7 day delay from center of 8-day window.

# Publications

- Publications
  - Fore, A., S. Yueh, W. Tang, B. Stiles, and A. Hayashi (2016). Combined Active/Passive Retrievals of Ocean Vector Wind and Sea Surface Salinity with SMAP, IEEE Trans. Geoscience and Remote Sensing, doi: 10.1109/TGRS.2016.2601486.
  - Yueh, S., A. Fore, W. Tang, H. Akiko, B. Stiles, N. Reul, Y. Weng and F. Zhang, (2016): SMAP L-band passive microwave observations of ocean surface wind during severe storms, *IEEE Trans Geosci. Remote Sens.*, doi:10.1109/TGRS.2016.2600239.
  - Wenqing Tang, Alexander Fore, Simon Yueh, Tong Lee, Akiko Hayashi, Alejandra Sanchez-Franks, Brian King, Dariusz Baranowski, and Justino Martinez (2017): "Validating SMAP SSS with in situ measurements," Remote Sensing of Environment, doi:10.1016/j.rse.2017.08.021
  - A. G. Fore, et al., "SMAP Radiometer-Only Tropical Cyclone Intensity and Size Validation", in IEEE Geoscience and Remote Sensing Letters, doi:10.1109/LGRS.2018.2849649

# SMAP GMF vs Aquarius GMF: A0; T12323



Legend:
- SMAP A0 eH
- AQ A0 eH
- AQ A0 eH adj
- SMAP A0 eV
- AQ A0 eV
- AQ A0 eV adj

SMAP and Aquarius roughness model agree well for <20 m/s

$$e = e_0 + e_1 \cos\phi + e_2 \cos 2\phi$$

x-axis: WindSAT Wind Speed [m/s]

y-axis: Excess Surface Emissivity

Wind Speed bias versus SFMR rain rate (SFMR spd > 20 m/s)

Insufficient data

SFMR 60 km average
SFMR > 20 m/s
Match-up time within 360 min

SMAP TB Wind Speed – Averaged SFMR Wind Speed [m/s]
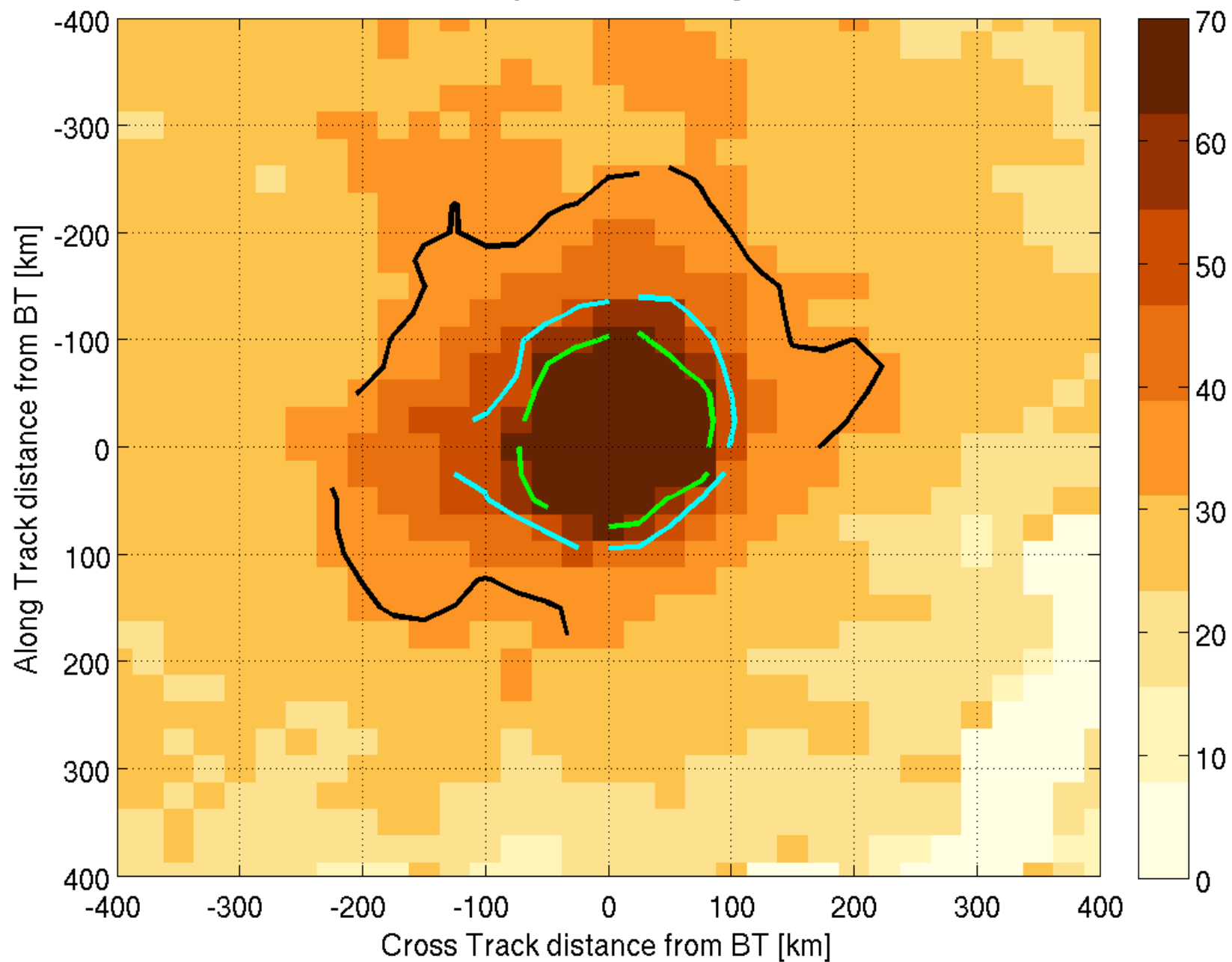
Averaged SFMR Rain Rate [mm/hr]

SMAP Wind Speed [knots]; LEE 14169
black lines - 34 kt; cyan lines - 50 kt; green lines - 64 kt
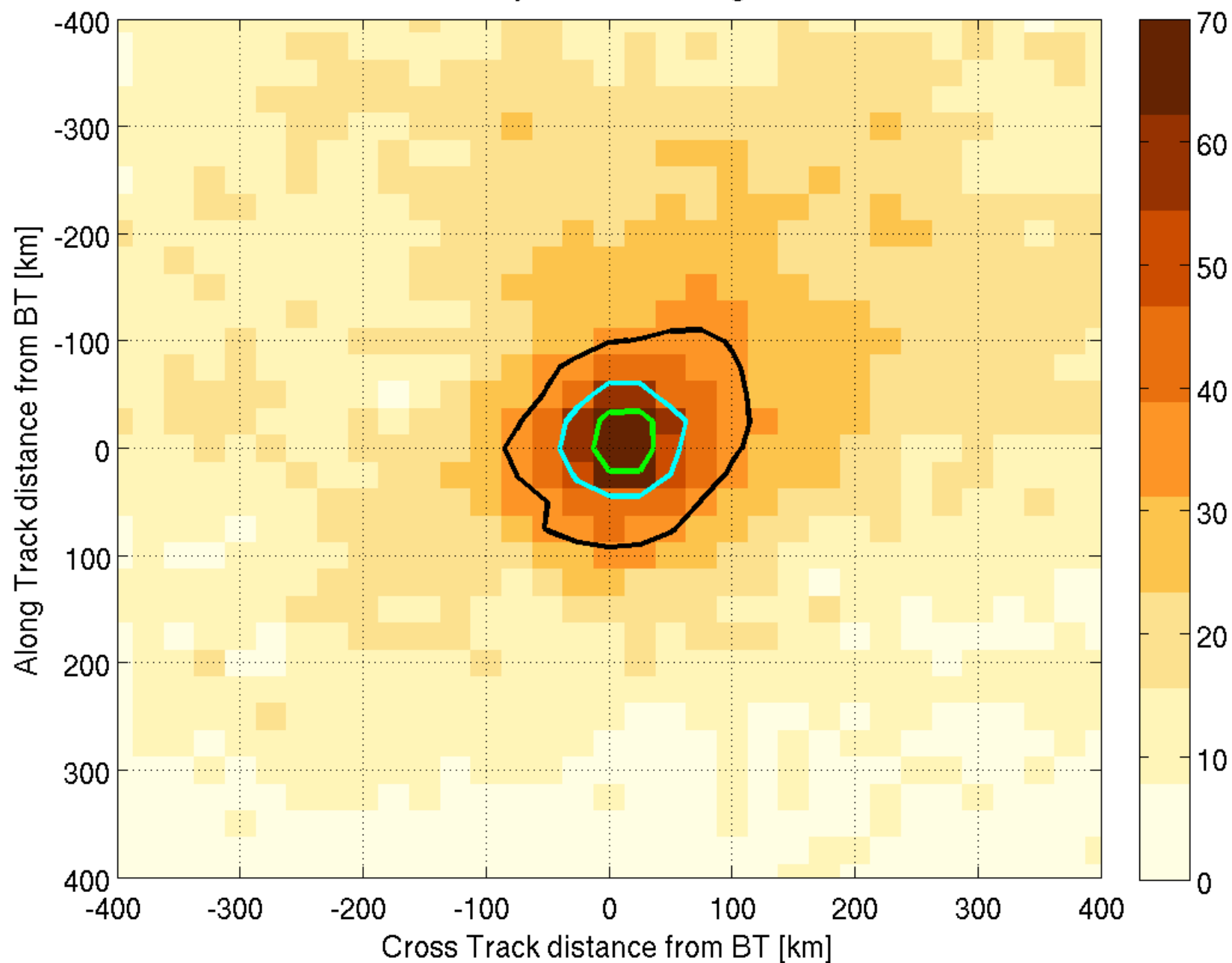
SMAP Wind Speed [knots]; IRMA 13862
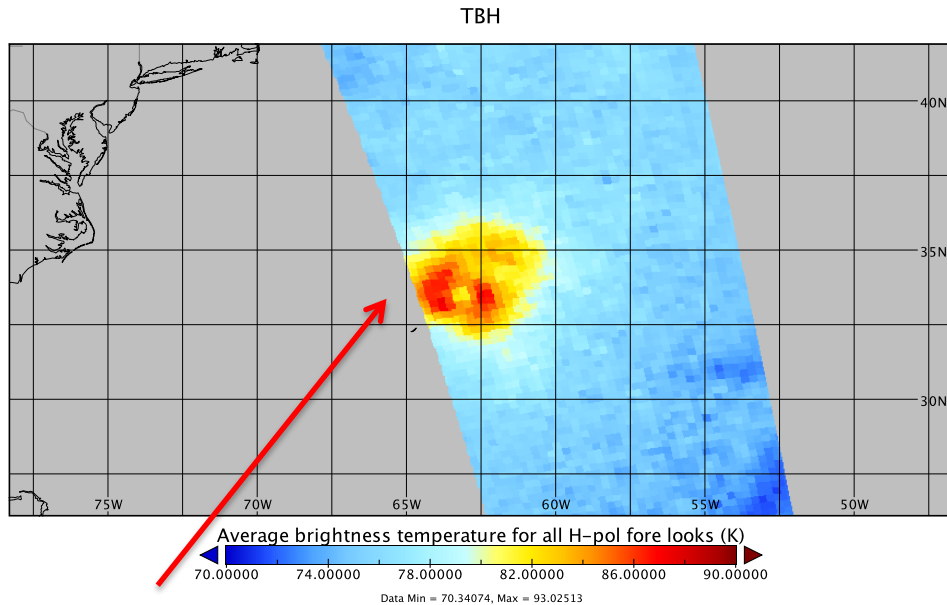black lines - 34 kt; cyan lines - 50 kt; green lines - 64 kt

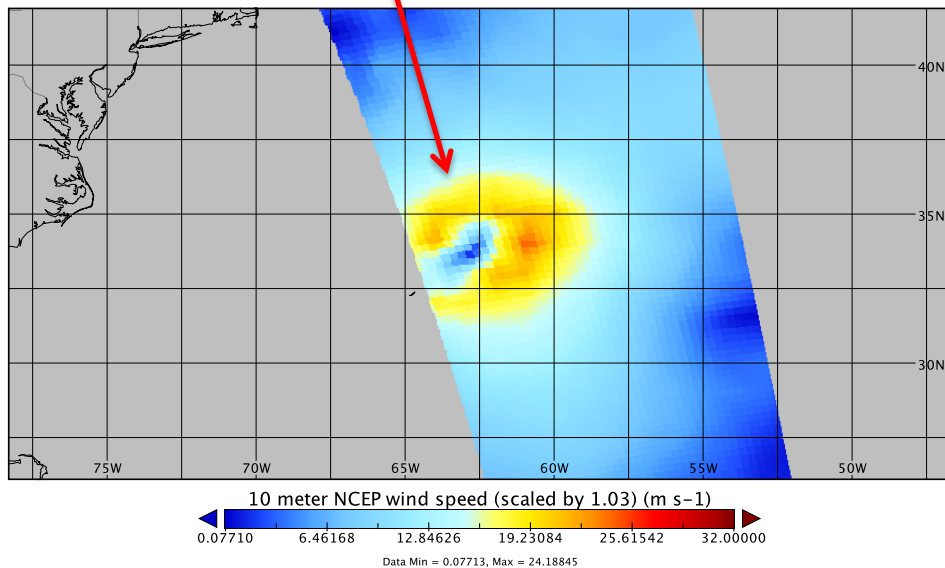Shape of storm is better represented using forecast data instead of interpolation of 6 hour now casts.

Leads to improve SSS retrievals near storms.
Particular improvement at high latitudes.
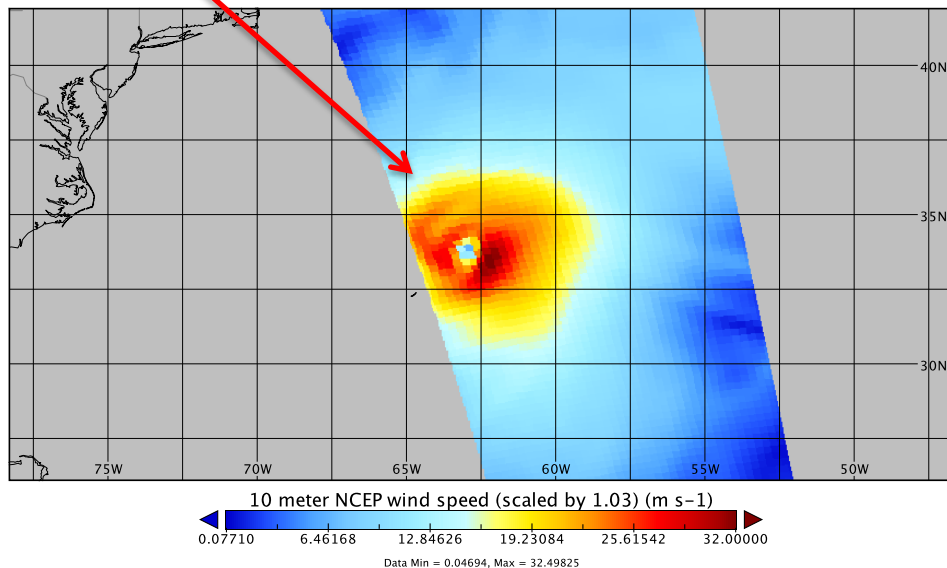
Smearing of eye in v3 ancillary winds.

V4 ancillary winds preserve shape



TBH

Average brightness temperature for all H-pol fore looks (K)

70.00000    74.00000    78.00000    82.00000    86.00000    90.00000

Data Min = 70.34074, Max = 93.02513

10 meter NCEP wind speed (scaled by 1.03)

10 meter NCEP wind speed (scaled by 1.03) (m s−1)

0.07710    6.46168    12.84626    19.23084    25.61542    32.00000

Data Min = 0.07713, Max = 24.18845

10 meter NCEP wind speed (scaled by 1.03)

10 meter NCEP wind speed (scaled by 1.03) (m s−1)

0.07710    6.46168    12.84626    19.23084    25.61542    32.00000

Data Min = 0.04694, Max = 32.49825

SMAP Salinity Difference to HYCOM

Improvement at high winds due to change in model winds.

v4 TB–Only Bias: 0.072
v3 TB–Only Bias: 0.002
v4 TB–Only RMS: 0.717
v3 TB–Only RMS: 0.719

Salinity Difference [psu]

WindSat / SSMI/S Wind Speed [m/s]